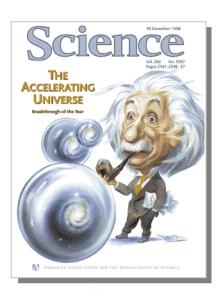
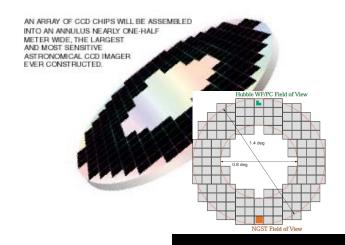
Supernova Cosmology & The Accelerating Universe



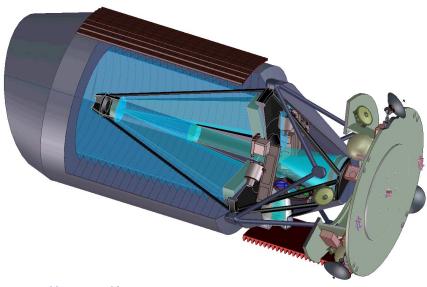
• Supernova Cosmology



• R&D, Key Technologies



• SuperNova /Acceleration Probe



Talk Outline:

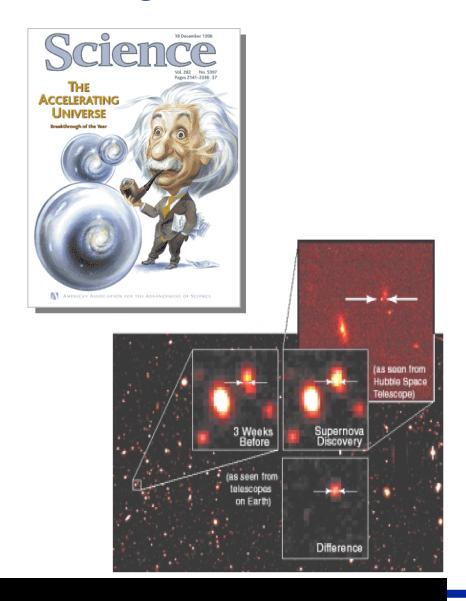
- Supernova Cosmology
- The Accelerating Universe
- SuperNova / Acceleration Probe
- SAGENAP
- Mission Overview
- Instrumentation
- R&D Activities
- Summary

Presented by: Michael Levi

Science Breakthrough of '98

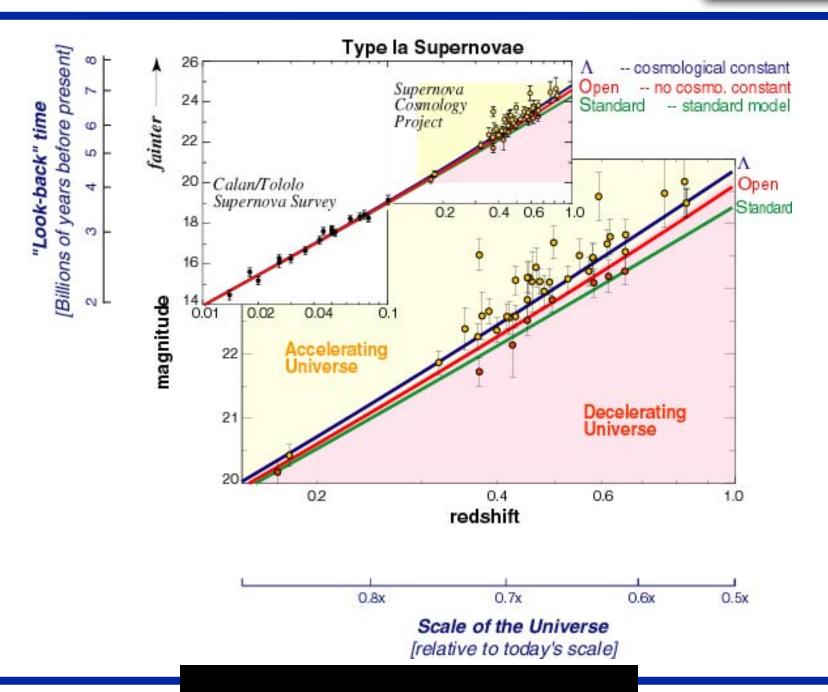


Science's Breakthrough of the Year: The Accelerating Universe



Key Result favoring Accelerating Universe

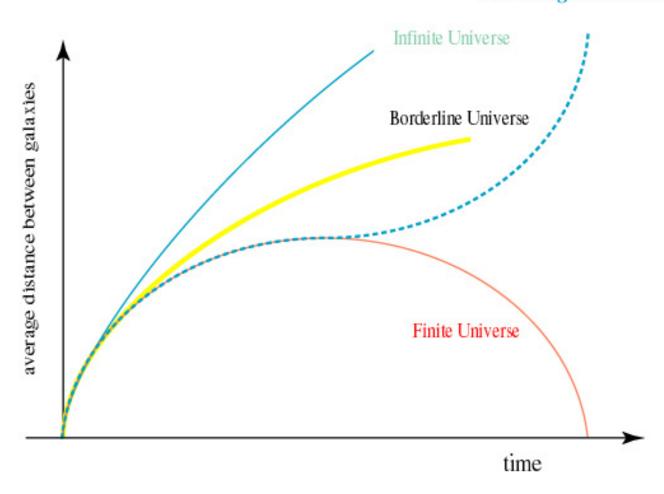




Effect of Cosmological Constant on the Fate of the Universe



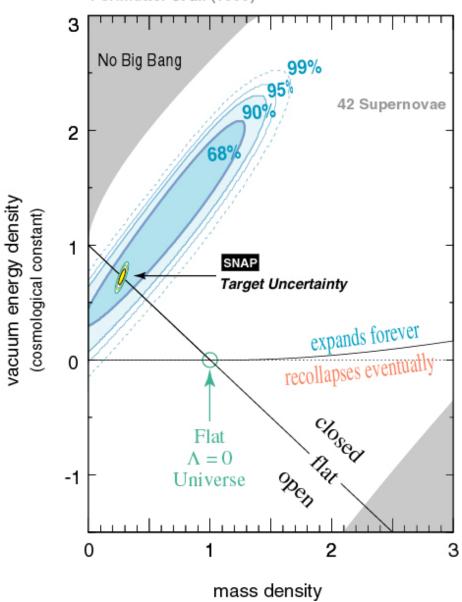
Universe with a Positive Cosmological Constant



Cosmological Constant







Fundamental Questions



Fundamental Questions:

- Will the universe last forever?
- *Is the universe infinite?*
- What is the universe made of?

An unusual moment in human history:

At the beginning of this century, Einstein developed the conceptual tools to address these questions empirically.

In the past decade or so, technology has advanced to the point that we can now make the measurements that begin to answer these fundamental questions.

Progress is now being made with large scientific programs, including the Supernova Cosmology Project and the Cosmic Microwave Background satellites: COBE, MAP, and PLANCK.

"Dark Energy"



The implications of an accelerating universe:

- 1. The expansion is not slowing to a halt and then collapsing (i.e., the universe is *not* "coming to an end"). In the simplest models, it will expand forever.
- 2. There is a previously unseen energy pervading all of space that accelerates the universe's expansion.

This new accelerating energy ("dark energy") has a larger energy density than the mass density of the universe (or else the universe's expansion wouldn't be accelerating). "Would be number one on my list of things to figure out" - Edward Witten

"Right now, not only for cosmology but for elementary particle theory this is the bone in the throat" - Steven Weinberg

1 T

"Maybe the most fundamentally mysterious thing in basic science"

- Frank Wilczek

"This is the biggest embarrassment in theoretical physics"

- Michael Turner

What we don't know is:

- 1. How much of mass density and dark energy density is there? I.e., how much dark matter and dark energy do we need to look for?
 - The answer to this question determines the "curvature" of the universe, and can tell us about the extent of the universe: infinite or finite.
- 2. What is the "dark energy"? Particle physics theory proposes a number of alternatives, each with different properties that we can measure. Each of the alternative theories raises some important questions/problems of fundamental physics.

Introduction to SNAP



- The SuperNova / Acceleration Probe (SNAP) conceived in March 1999
- SNAP still in embryonic stage
 - Recent SAGENAP review (joint DOE/NSF) was successful
 - <u>Scientific Assessment Group for Experiments in Non-Accelerator Physics</u>
 - R&D funding received in June 2000

SNAP Proposal



SNAP Proposal Signatories



D. Curtis, G. Goldhaber, J. Graham, S. Harris, P. Harvey, H. Heetderks, A. Kim, M. Lampton, R. Lin, D. Pankow, C. Pennypacker, A. Spadafora, G. Smoot Univ ersity of California, Berk eley, CA, USA

Samuel Silver Space Sciences Laboratory



G. Aldering, S. Deustua, W. Edwards, B. Frye, D. Groom, S. Holland, D. Kasen, R. Knop, R. Lafever, M. Levi (co-PI), P. Nugent, S. Perlmutter (PI), K. Robinson Lawrenc e Berk eley National Laboratory, Berk eley, CA, USA

P. Astier, J.F. Genat, D. Hardin, J-M. Levy, R. Pain, K. Schamahneche LPNHE, CNRS-IN2P3 and Univ ersity Paris VI & VI I, Paris, France





A. Baden, J. Goodman, G. Sullivan Univ ersity of Maryland, College Park, M.D., USA

R. Ellis, M. Metzger California Institute of Technology, Pasadena, CA, USA



Univ ersity of Chicago, Chicago, IL, USA



Space Telescope Sciences Institute, Baltimore, M.D., USA



Cornell University, Ithac a, NY, USA

L. Bergstrom, A. Goobar

Univ ersity of Stockholm, Sweden



Institute for Astronom y, Univ ersit y of Edin burgh, UK

C. Lidman

Europ ean Southern Observatory

J. Rich

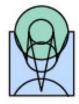
CEA/D A PNIA, Saclay France

A. Mourao

CENTRA, Instituto Superior Tecnico, Lisbon, Portugal







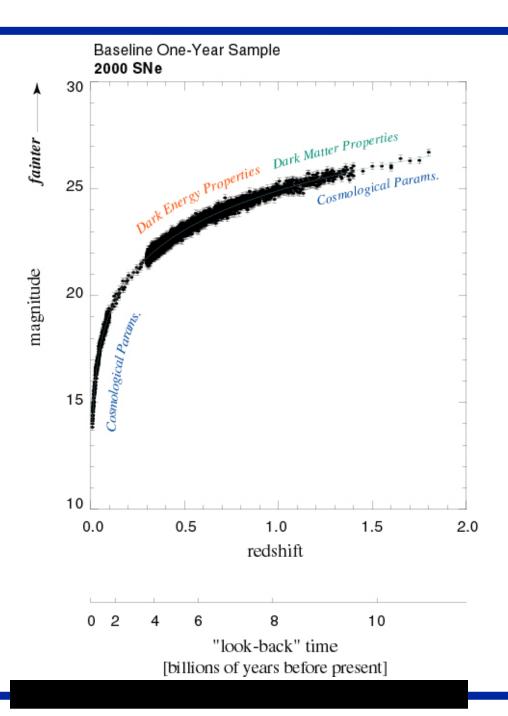






SNAP: One year sample of 2000 SNe





Purpose of SNAP



For a definitive measurement to provide a pillar of our cosmological theory requires

- a much larger statistical sample of supernovae
- with much better controlled measurements
- over a much larger range of redshifts

that cannot be obtained with existing or planned facilities.

SNAP Science Topics



Cosmological Parameters, Dark Matter...

- Type Ia supernova calibrated candle
- Type II supernova expanding photosphere
- Weak lensing
- Strong lensing statistics. Ω_{Λ}
- Galaxy clustering, P(k)
- z > 1 clusters and associated lensing

...and Beyond

- GRB optical counterparts: rates, lightcurves, and spectra
- MACHO optical counterparts by propoer motion
- Galaxy populations and morphology to co-added m=32
- Target selection for NGST
- Kuiper belt objects
- Supernova rates, star formation rates
- Supernova phenomenology studies
- Low surface brightness galaxies, luminosity function

Archive data distributed:

deeper than Hubble Deep Field and 7000 times larger

Control of Systematic Errors



What makes the supernova measurement special? Control of systematic uncertainties.

However,

for a definitive supernova cosmology measurement...

it is necessary but NOT sufficient to find and study

- more Sne Ia
- farther Sne Ia

because the statistical uncertainty is already within a factor of tow of the systematic uncertainty.

The most demanding SNAP data requirements are devoted to eliminating and controlling all systematic uncertainties.

Mission Requirements



- Observe 2000 type 1a Supernova per year
 - Quantity: Field-of-View 1 square degree
 - Quality: 2% photometry, 15 angstrom resolution from 350 1700 nm
 - Distribution: Ability to detect Supernovae as far away as 10 billion light years
- SNAP design meets these scientific objectives
 - Mirror: 2 meter aperture sensitive to light from distant SN
 - Camera: 1 billion pixels
 - Spectroscopy: 3 arm optical and infrared spectrograph
 - Orbit: high orbit to permit passive cooling, outside radiation belts, close enough to allow high rate data 50 Mb/s transmission link

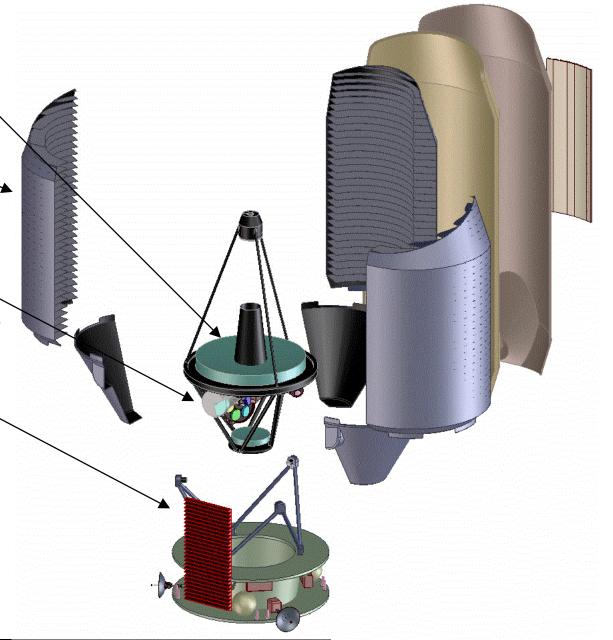
Mission Overview



Simple Observatory consists of:

- 1) 3 mirror telescope w/ separable kinematic mount
- 2) Baffled Sun Shade w/ body mounted solar panel and instrument radiator on opposing side
- 3) Instrument Suite
- 4) Spacecraft bus supporting telemetry (multiple antennae), propulsion, instrument electronics, etc

No moving parts (ex. filter wheels, shutters), rigid simple structure.



SAGENAP



In summary, the SAGENAP discussions indicate enthusiastic agreement by the panel that the science goals are on questions of great importance to physics and cosmology. Further, it was considered that at the present stage in the measurement of the cosmological parameters, new experimentation is fully warranted and that the SN Ia technique will continue to play a crucial part. The quality of the document presented was felt to be impressive, particularly for a project in its early stages. The panel Members were favorably impressed with the proposers' consideration of the sources of systematic error and were largely convinced that a fully satellite-based experiment is likely to be the preferred approach. The panel noted that the requirements for spectroscopy in space are stringent and the demands on CCD performance and utilization are severe. Consequently, a thorough investigation of the technical risks of this and all other detector systems should be re-evaluated in Phase I...

There was unanimity on SAGENAP that a substantial R&D program is required soon to insure a successful SNAP experiment. There was also agreement that the entire project should not be fully endorsed until a more complete R&D program and its management is presented and reviewed by an appropriate technical group. It was also widely supported that, if the DOE and NSF decide to conduct such a review, SAGENAP suggests that interim funds be provided to speed the preparations for a review and to enable the forward movement of this important experiment...

SNAP Task Breakdown



- Instruments
 - Optical Imager
 - IR Imager
 - Spectroscopy
 - Electronics
 - Data Handling
- Telescope
 - Optics
 - Mechanical structure
 - Optical Bench
 - Integration & Test
- Operations
 - Operations Center
 - Ground Antenna
 - Preparation for Data Handling
 - Mission Operations

- Science Team
 - Science Requirements
 - Data Analysis
 - Education and Public Outreach
 - Science Working Groups
- Spacecraft
- Mission Integration & Test
 - Instrumentation/Telescope
 - Scientific Payload/Spacecraft
 - Satellite/Launch Vehicle

R&D Activities in 2000



- Demonstration and Validation
 - initiate prototyping of CCD's, and imager
 - pursue alternative focal plane options, testbedding facilities
- Mission Requirements and Design Optimization
 - refine reference mission and revise mission requirements
 - optimization of orbit and environmental design issues
 - conduct and document first-order trade studies
 - develop integration and test plans
 - risk analysis and mitigation
 - produce Telescope Assembly draft requirements/specifications
- Project Management
 - engineer, define, and establish system acquisition strategy
 - develop cost models and cost estimating relationships
 - develop integrated schedule
 - engineer, define, and establish system acquisition strategy
 - establish DOE/NSF, NASA working relationships

Instrumentation Requirements



- Need consistent uniform data set where selection criteria can be applied and systematic sources can be analyzed and factored.
- Minimum data set criteria:
 - 1) discovery within 2 days of explosion (peak + 3.8 magnitude),
 - 2) 10 high S/N photometry points on lightcurve,
 - 3) lightcurve out to plateau (2.5 magnitude from peak),
 - 4) high quality spectrophotometry at peak,
 - 5) IR spectra.
- How to obtain both data quantity AND data quality?

Batch processing techniques w/ wide field imager -- large multiplex advantage Mostly preprogrammed observations, fixed fields / spin filter wheel

No Trigger (z < 1.2)

Very simple experiment, passive, almost like accelerator expt.

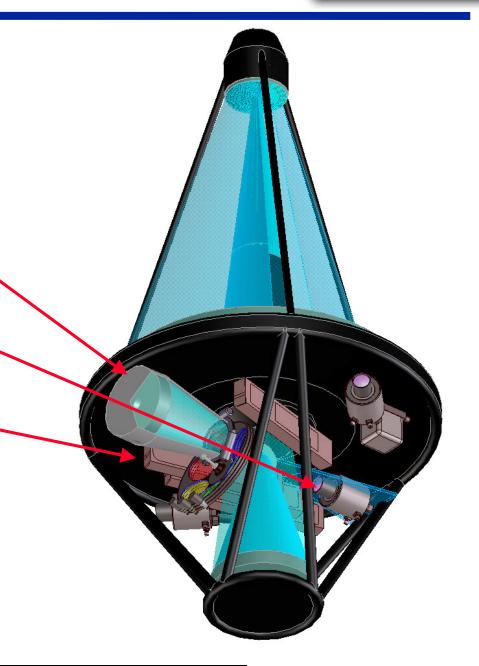
Well calibrated photometry and spectroscopy

SNAP Instrumentation Suite



Key Instruments:

- 1) GigaCAM 1 sq. deg FOV 128 3kx3k CCD's
- 2) IR Photometer (small field of view)
- 3) 3-channel spectrograph 350-600 nm, 550-1000 nm, 900-1700 nm



Optical Photometry Requirements



Field-of-view 1° x 1°

Plate Scale 1 pixel ~ 0.1 arcsec

Pixelization 32k x 32k CCD mosaic

Wavelength coverage 350nm - 1000nm

Detector Type High-Resistivity P-channel CCD's

Detector Architecture 2k x 2k, or 2k x 4k

Detector Temperature 150 K

Quantum Efficiency 65% 1000nm, 92% 900nm, >85% 400-800nm

Read Noise 4 e- @100kHz

Exposure Time up to 1000 sec (single exposures)

Number of Frames 1 to 24

Dark Current 0.08 e-/min/pixel

Readout Time 20 sec

Limiting Magnitude 30th magnitude in Z-band

Exposure control Mechanical shutter

Filter Wheel 15 bands (U, V, R, I, Z, & 10 special filters)

Fully-Depleted CCD's

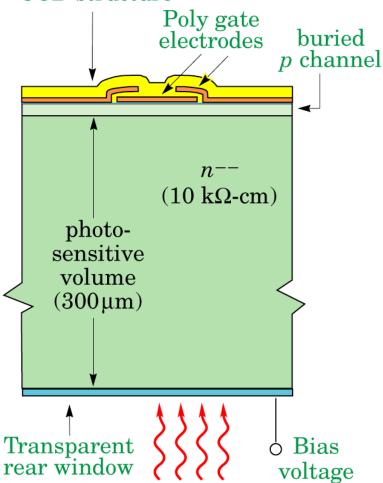


The New Approach:

Make a thick CCD on a high-resistivity n-type substrate, to operate fully depleted with rear illumination.

3-phase

CCD structure



Advantages:

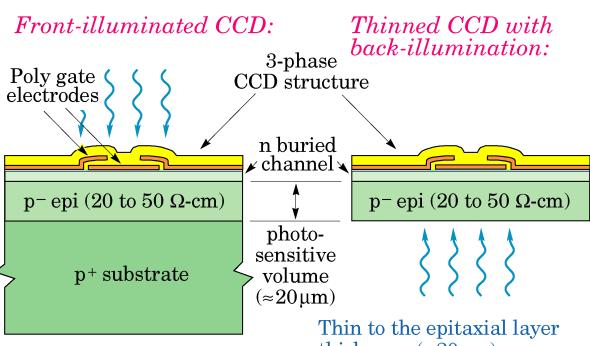
- 1) Conventional MOS processes with no thinning=> "inexpensive"
- 2) Full quantum efficiency to $> 1 \mu m => no fringing$
- 3) Good blue response with suitably designed rear contact
- 4) Radiation tolerant

Disadvantages:

1) Enhanced sensitivity to radiation (x-rays, cosmic rays, radioactive decay)

Typical CCD's





Drawbacks:

- 1) Poor blue response due to absorption in polysilicon gate electrodes
- 2) Poor near-IR response due to thinness of the epitaxial layer
- 3) Interference patterns due to gate structure

thickness (≈20µm)

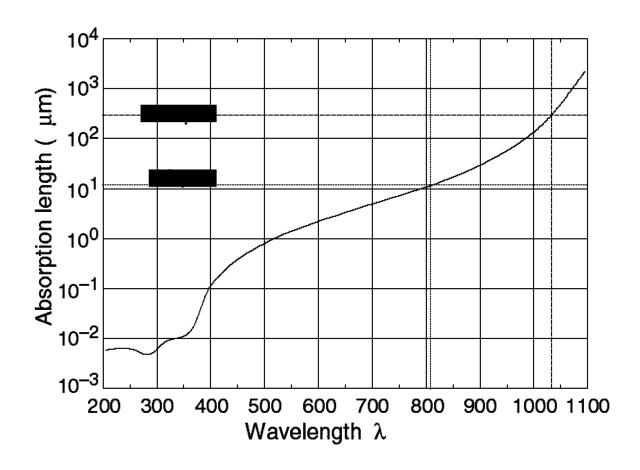
Drawbacks:

- 1) Thinning is difficult and expensive
- 2) Poor near-IR response
- 3) Interference (fringing)
- 4) Lateral diffusion in fieldfree region (degraded PSF)

CCD Technology

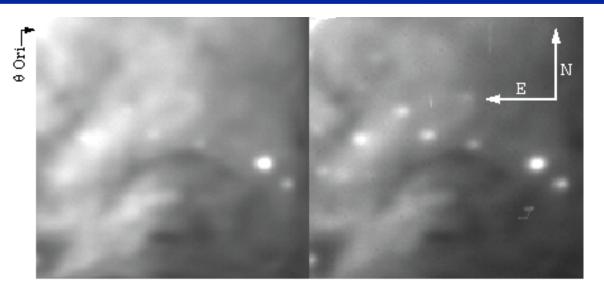


Photoactive region of standard CCD's are 10-20 microns thick Photoactive region of Fully-Depleted CCD's are 300 microns thick



Portrait Gallery from Lick Observatory LBNL CCD's



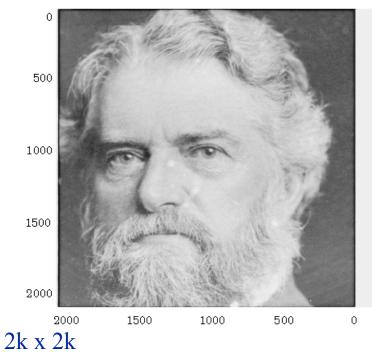


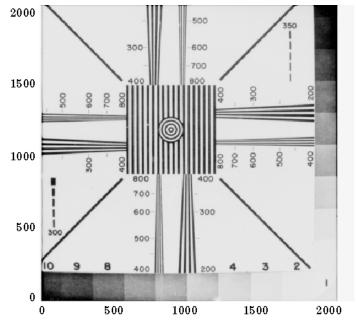
200x200 Lick Obs.

Orion

Left: R band

Rgt: Z band

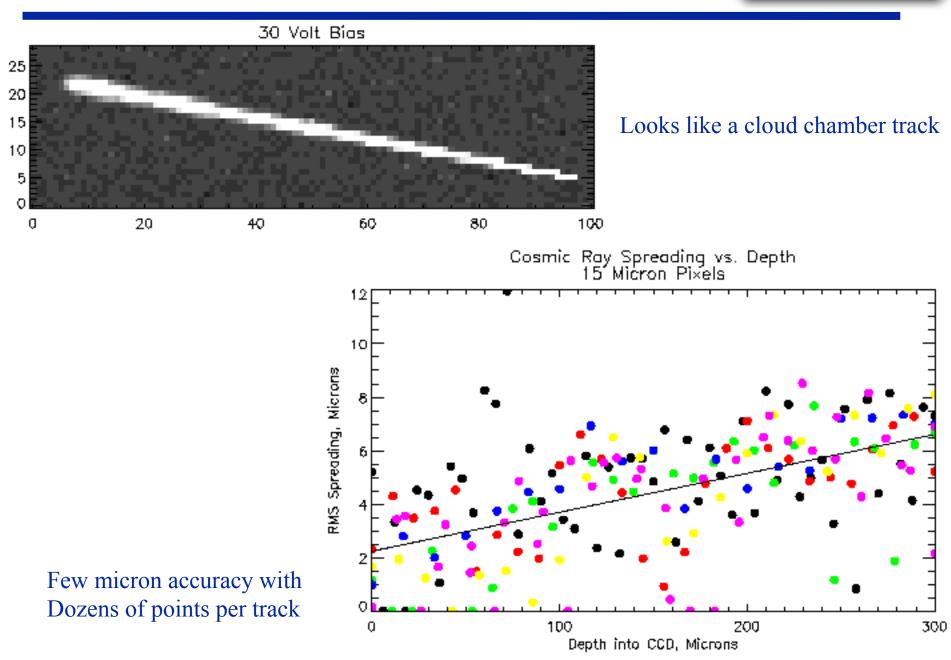




2k x 2k

Cosmic Ray Image

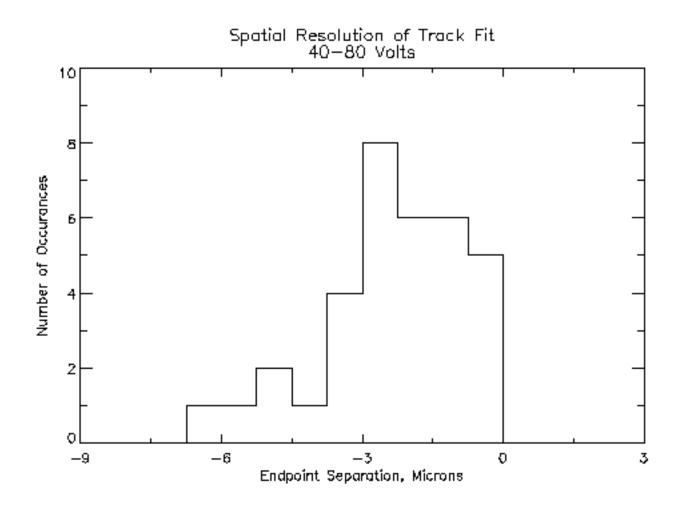




Spatial Accuracy



Cut track in half and fit separately, look at track separation of endpoints, indicates $\sigma = 1.2 \mu m$

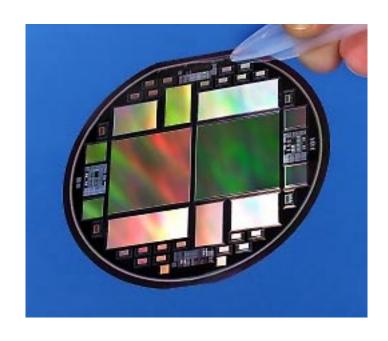


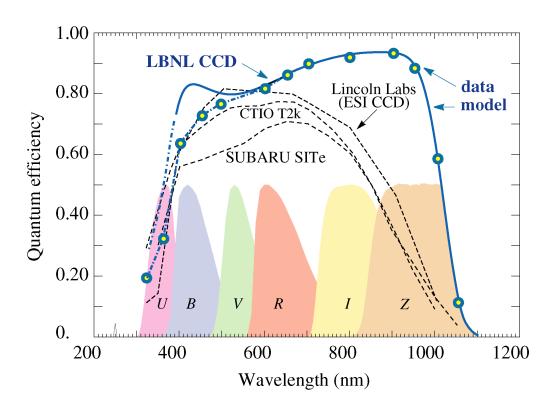
CCD's for GigaCam



- New kind of CCD developed at LBNL
- 2k x 2k (4 Megapixels/device) design successful, meets SNAP performance requirements
- Commercialization
- Current in house fabrication

2k x 4k for Eschellette Spectrograph and Imager (Keck)





CCD Status



- In house 2k x 2k (15 µm pixels) design successful, meets SNAP performance requirements
- Commercialization at CCD foundry

2k x 2k (15 µm pixels) successful, in test at Lick Two separate processing runs (1) "standard"; (2) modified process recipe Current run of 4" wafers; will be followed immediately by run of 6" wafers

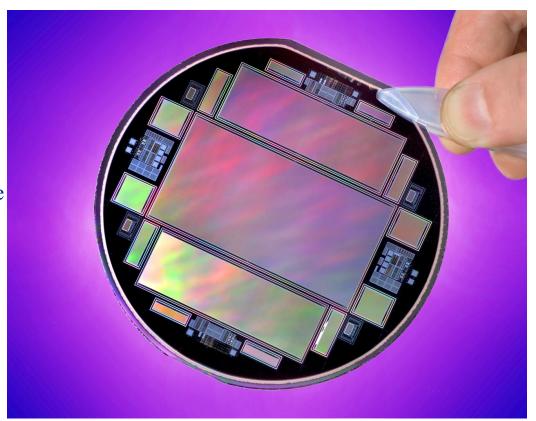
• Current in house fabrication completing now

2k x 4k (15 µm pixels) for Eschellette Spectrograph and Imager (Keck)

 \sim 2k x 4k (12 μ m pixels)

 \sim 2k x 4k (10.5 μ m pixels)

- Requires further extensive radiation testing (already tested at LBNL 88" cyclotron to 20% of SNAP lifetime exposure w/o degradation) & large scale prototyping
- Complete commercialization

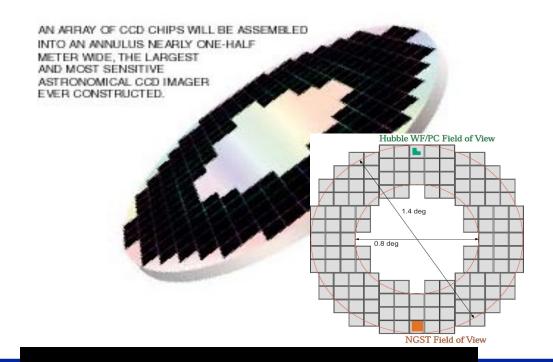


GigaCAM



GigaCAM, a one billion pixel array

- Depending on pixel scale approximately 1 billion pixels
- ~128 Large format CCD detectors required
- Looks like the SLD vertex detector in Si area (0.1 0.2 m²)
- Larger than SDSS camera, smaller than BaBar Vertex Detector (1 m²)
- Collaboration has lots of experience in building very large silicon detectors and custom readout electronics including radiation hard integrated circuits (should they be necessary).



BaBAR Silicon Vertex Detector (~1m² Si)

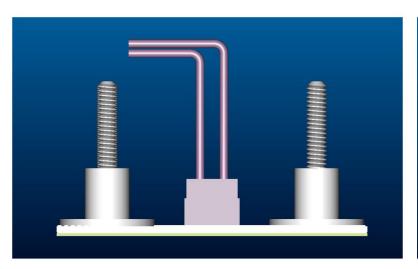


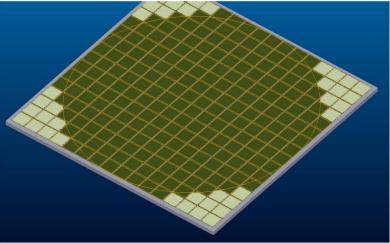


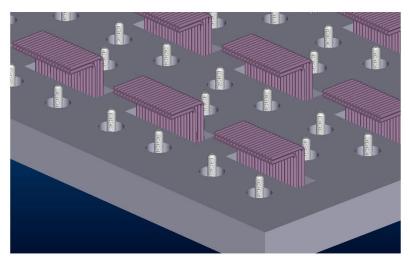
Imager Technology

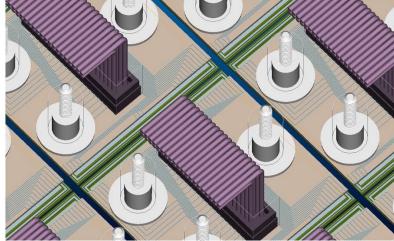


32K by 32K Optical Imager Array



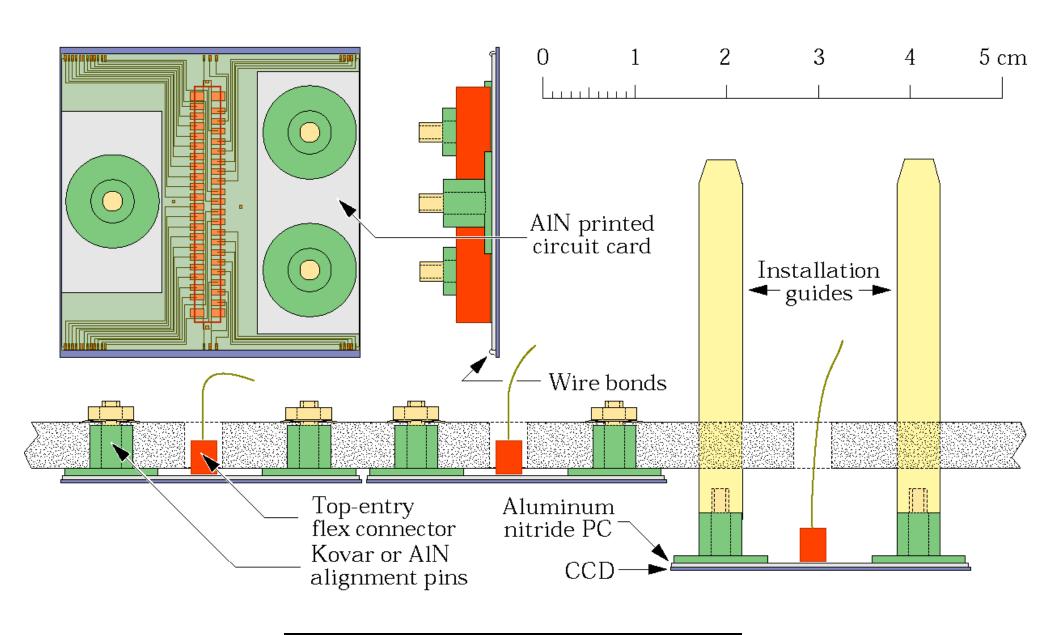






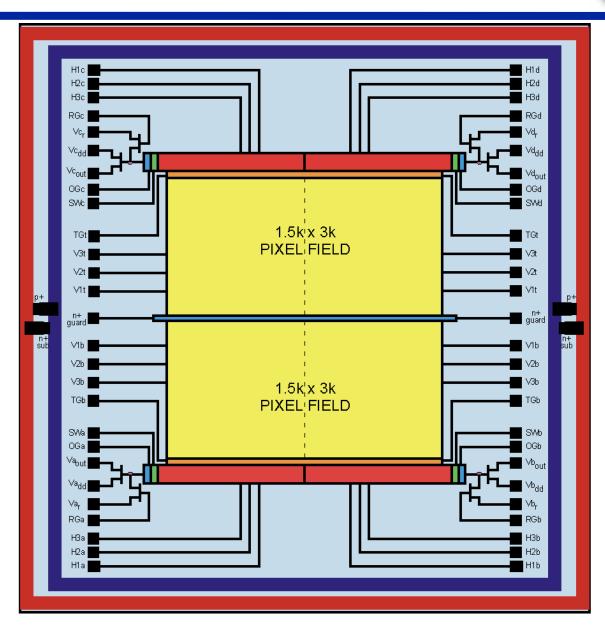
Mosaic Packaging





3kx3k CCD for SNAP

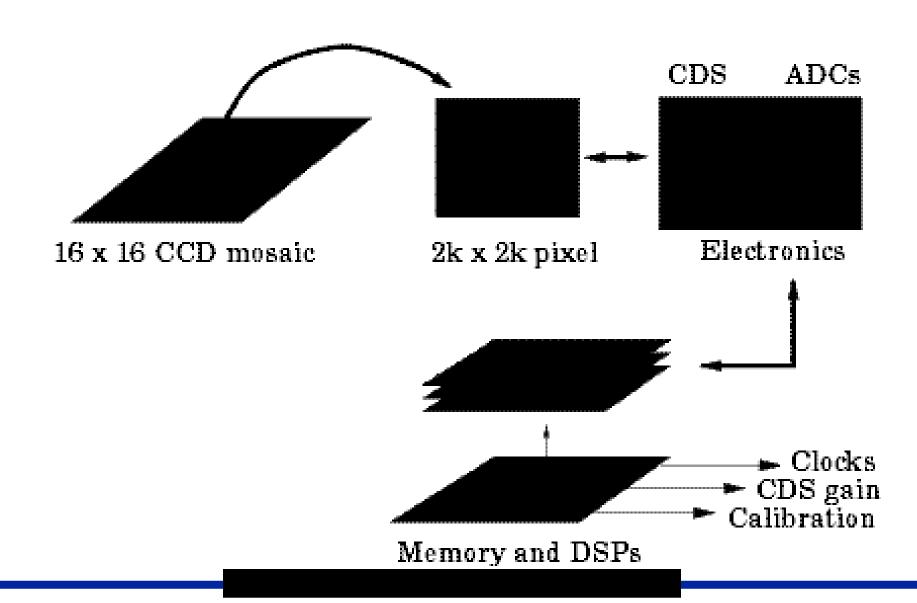


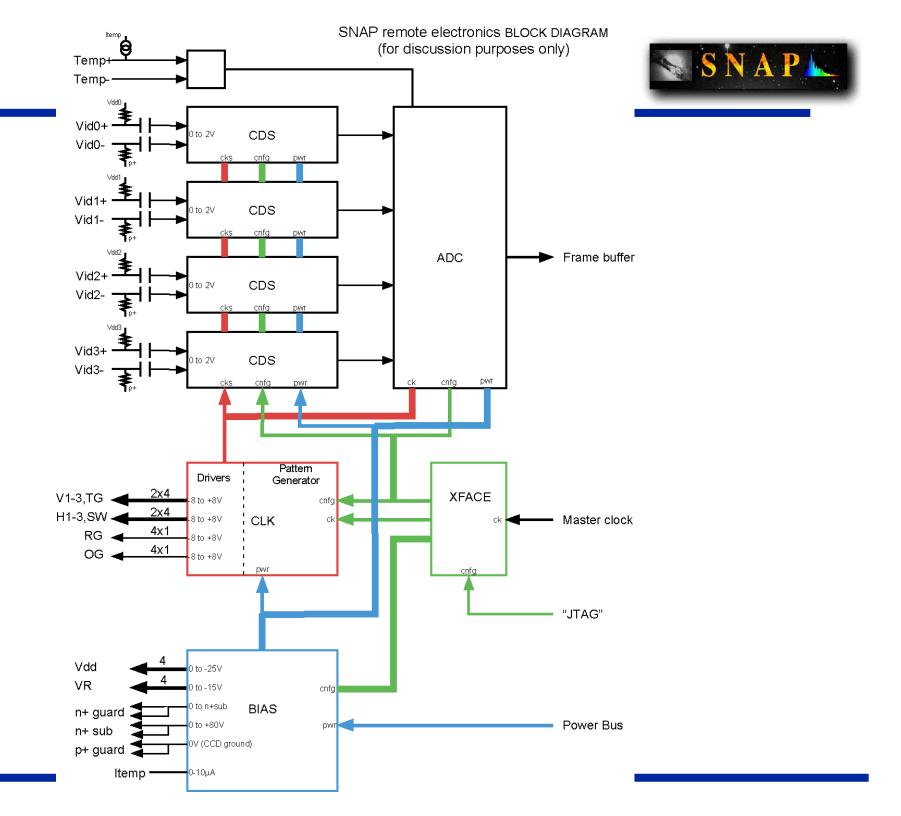


Electronics



GigaCAM Readout looks like high density vertex detector readout with 400 readout channels (two per CCD)

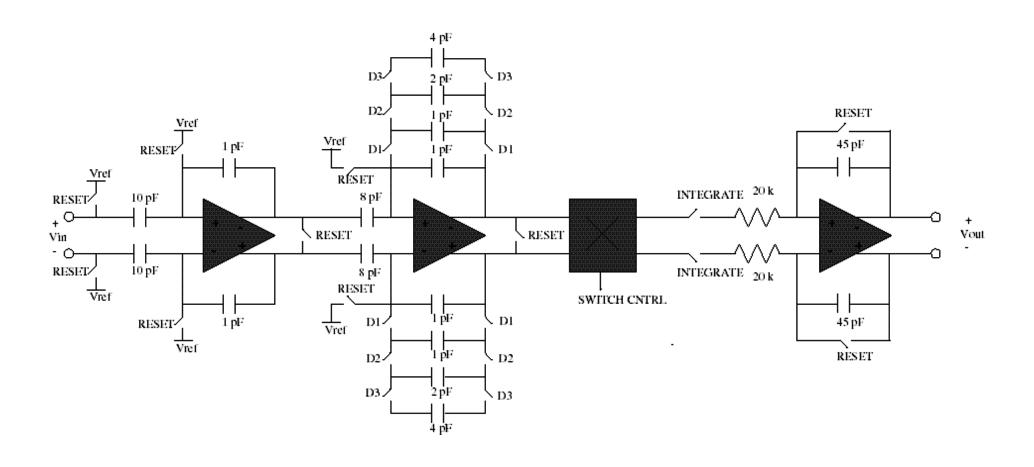


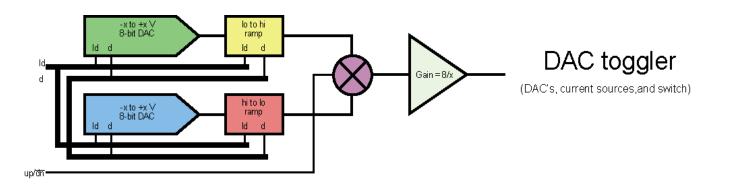


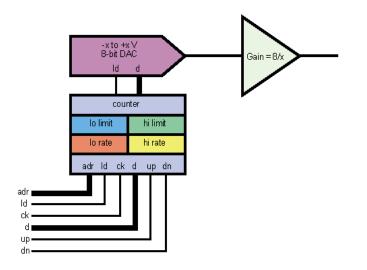
Electronics



Custom Readout - Correlated Double Sampler
Already in development (UCB/LBNL/Univ. Paris)

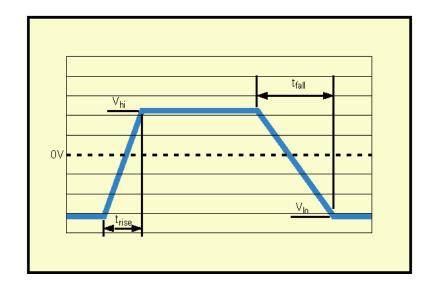






DAC ramper

(counter, rate dividers, comparators, and DAC).



Approaches to rise-time controlled, variable amplitude CCD clocking

IR Photometry Requirements



Field-of-view

Plate Scale

Wavelength coverage

Detector Type

Detector Architecture

Detector Temperature

Read Noise

Dark Current

Limiting Magnitude

Exposure control

Filters

10' x 10'

1 pixel ~ 0.1 arcsec

1000nm - 1700nm

HgCdTe (1.7 µm cut-off)

Mosaic of 2kx2k

130K (to achieve dark I)

6 e- (multiple samples)

3 e-/min/pixel

30th magnitude (AB)

Mechanical shutter

J&H, plus five special filters

3-arm Spectrograph Requirements



Optical:

Spectrograph architecture Integral field spectrograph, two arms Wavelength coverage 350-600 nm, 550-1000nm Spatial resolution of slicer 0.07 arcsec Field-of-View 2" x 2" Resolution 15A, 30A, 100A selectable **CCD** Detector Type 2k x 2k **Detector Architecture** Detector Array Temperature 150 K Quantum Efficiency 65% 1000nm, 92% 900nm, >85% 400-800nm Read Noise = 4 e - (2.100 kHz)

0.08 e-/min/pixel

IR:

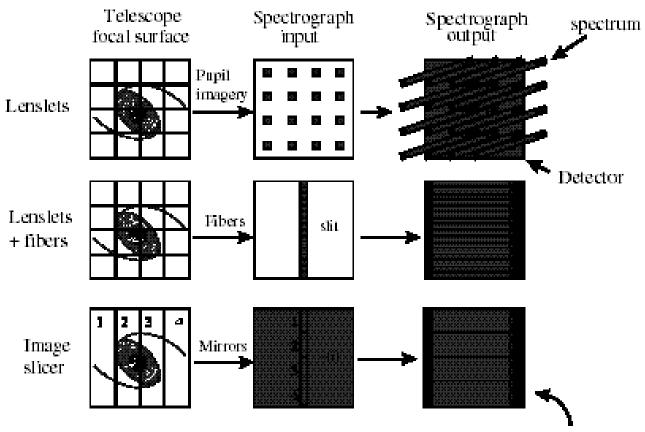
Dark Current

Spectrograph architecture Integral field spectrograph, one arm Wavelength coverage 900 to 1700 nm Spatial resolution of slicer 0.12 arcsec Field-of-View 2" x 2" Resolution 30A, 50A, 200A selectable Detector Type HgCdTe **Detector Architecture** 2k x 2k Detector Array Temperature 77 - 130 K (to achieve dark I) 56% @ 1000nm Quantum Efficiency Read Noise = 5 e- (multiple samples) Dark Current 1 e-/min/pixel

Spectroscopy Technology



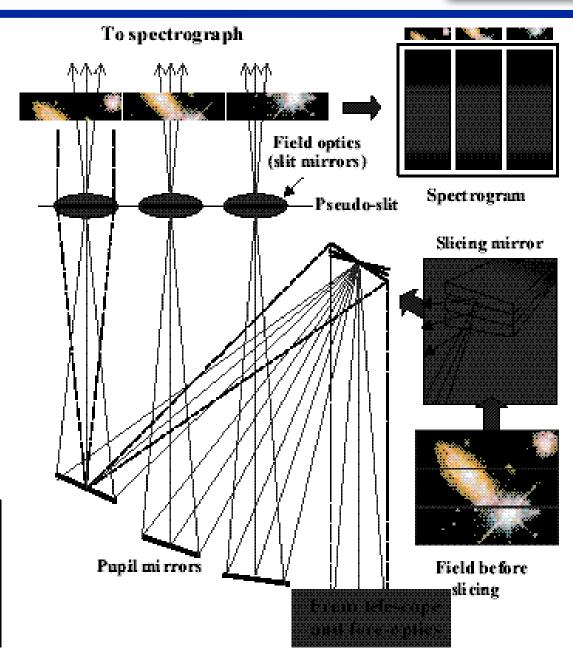
• Reflective Image Slicer (e.g. Palomar 200", NGST IFMOS)



Only the image slicer retains spatial information within each slice/sample

Integral Field Spectrograph for NGST





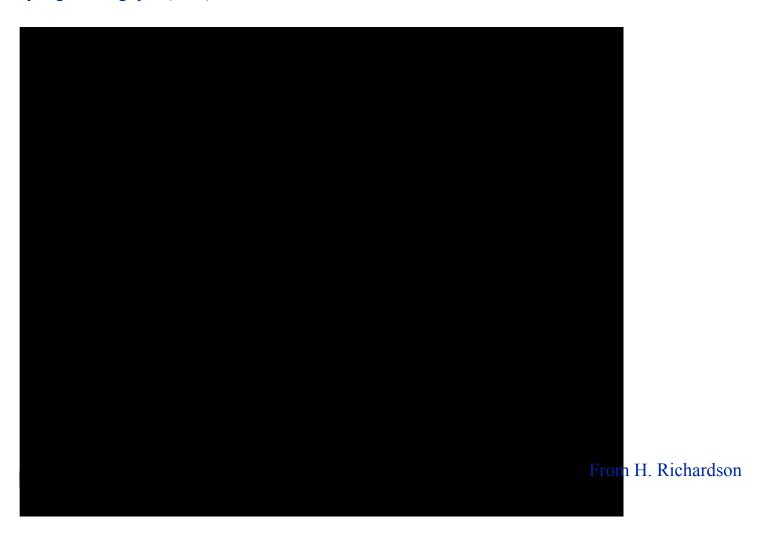
From LAS-NGST-IFMOS-004
O. Le Fevre, et.al - Laboratoire
d'Astronomie Spatiale in Marseilles



Integral Field Spectrograph for NGST



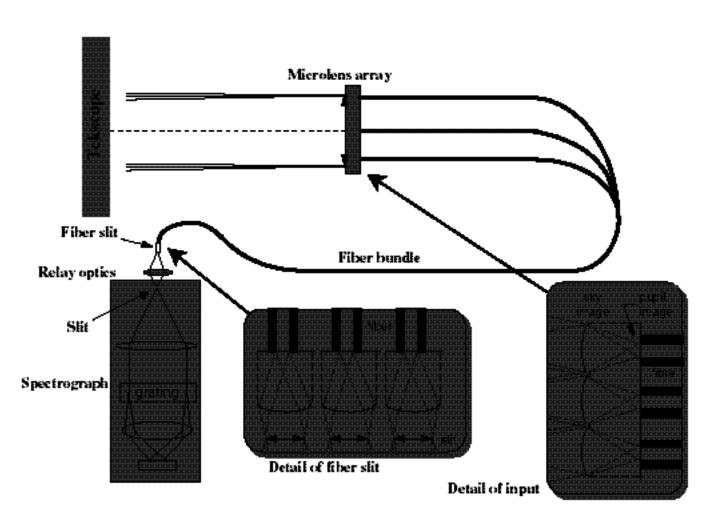
Solid Block Image Slicer Very high throughput (90%)

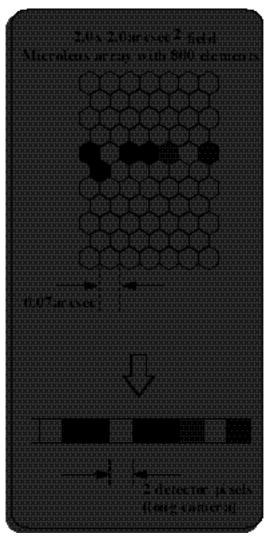


Spectroscopy w/ fibers



MicroLens Array:





From Haynes, astro-ph/9909017

Observatory Requirements



Aperture \sim 2.0 meter 1° x 1° Field-of-view Optical resolution diffraction-limited at 1 µm 350nm - 1700nm Wavelength Solar avoidance 70° Fields of study North and South Ecliptic Poles Image Stabilization Feedback from Focal Plane Focal Length 20 meter

Spacecraft is always at near normal incidence to sun

SNAP Optics Requirements



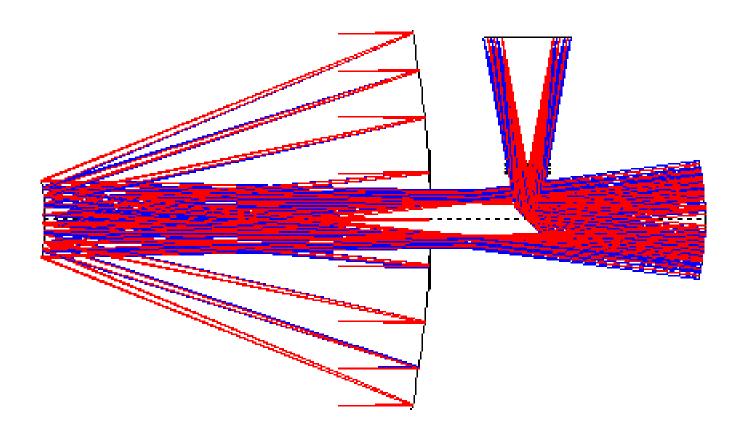
- Photometric accuracy and speed: 2 meter aperture
- Discovery rate: one square degree sky coverage
- CCD sampling & pixel size: 10 microns = 0.1 arcsecond
 - EFL=20 meters, speed=f/10
- SNR: diffraction limited at one micron wavelength
 - First Airy dark ring = 24.4 microns diameter
- CCD Array Fabrication: flat focal surface
- SNR and operational simplicity: achromatic optics
- Photometry: 15 contiguous bandpasses, 0.4 to 1.7 um
- Vehicle constraints: overall optics length <5 meters

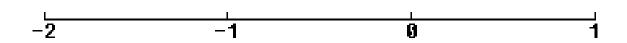
TMA55 Optics Details



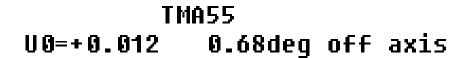
- Primary Mirror
 - diameter= 2000 mm; hole= 330mm
- Secondary Mirror
 - diameter= 424mm
- Tertiary Mirror
 - diameter=642mm
- Folding Flat Mirror
 - oval, 120mm x 192mm;
- Annular Detector Array
 - inner diameter 278mm, outer diameter 480mm

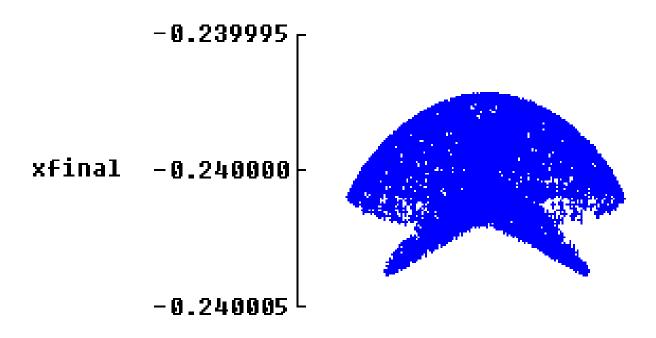




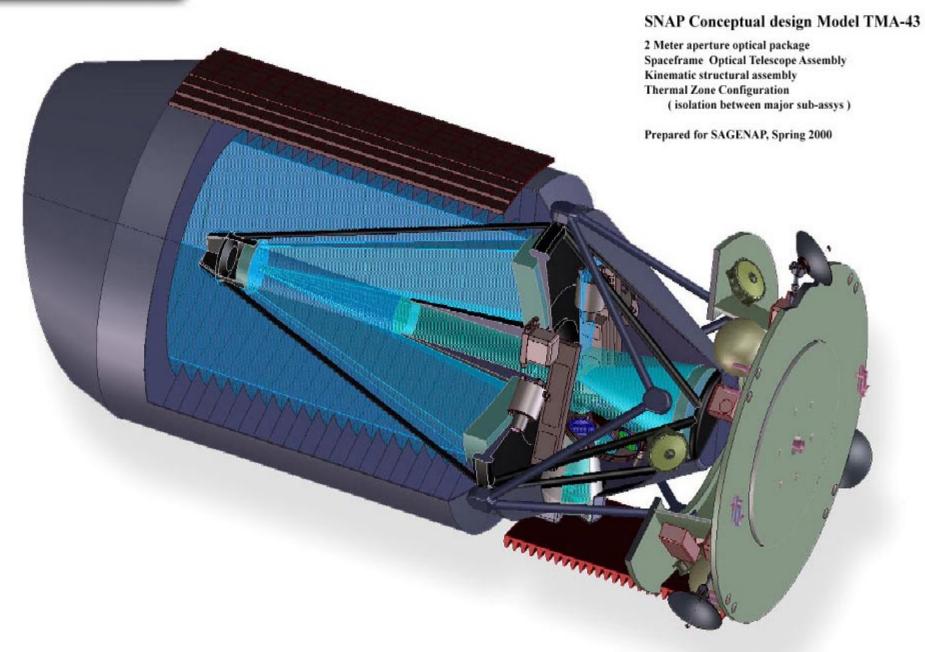










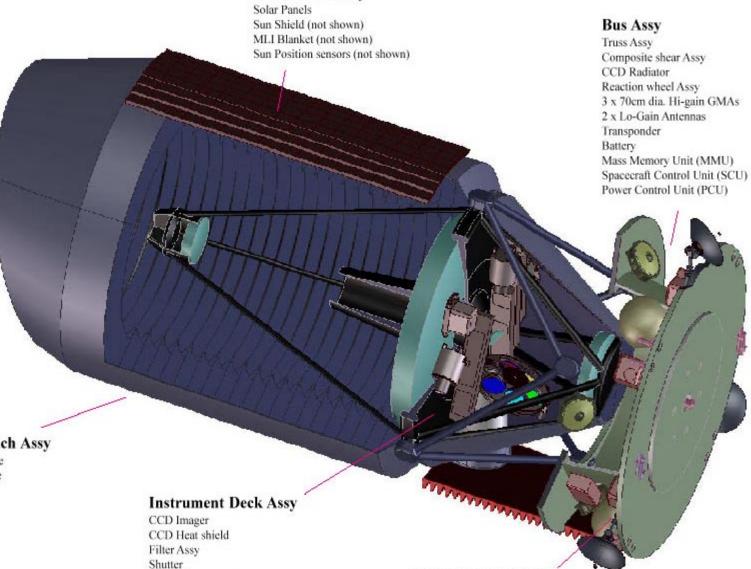




TMA-43

is shown here in one of several configurations.

TMA-51 and TMA-55 can also be accomodated. Both, however, have improved options and new requirements that are leading to the NEXT conceptual design.



Propulsion Deck Assy

12 x .5 lbf engines

1 x 5.0 lbf engine

Controls

3 x 47 cm dia. tanks

Heat Shield Assy

Star tracker cameras SNAP Star Guide camera

Gyro Assy

IR Spectro

Optical Spectro

Optical Bench Assy

Main Baffle Tube Secondary Baffle Inner Baffle Space Frame Light Shields



Launch Vehicles

Optical Packages

Candidates have been arranged approximately in descending order with respect to:

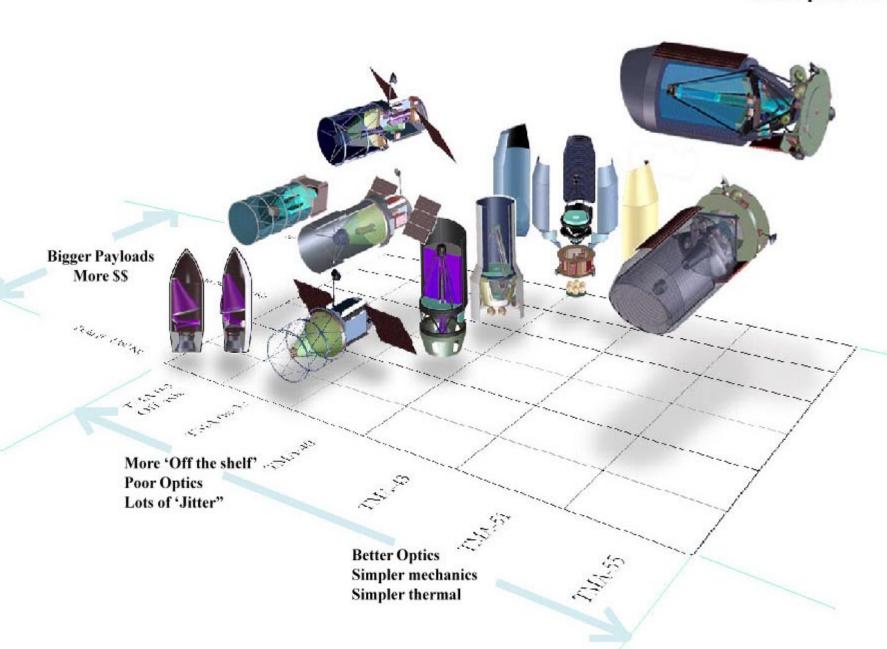
The candidates below have been worked up in enough detail to suggest plausible Payload

Trade Space Overview Launch vehicle vs Optical package

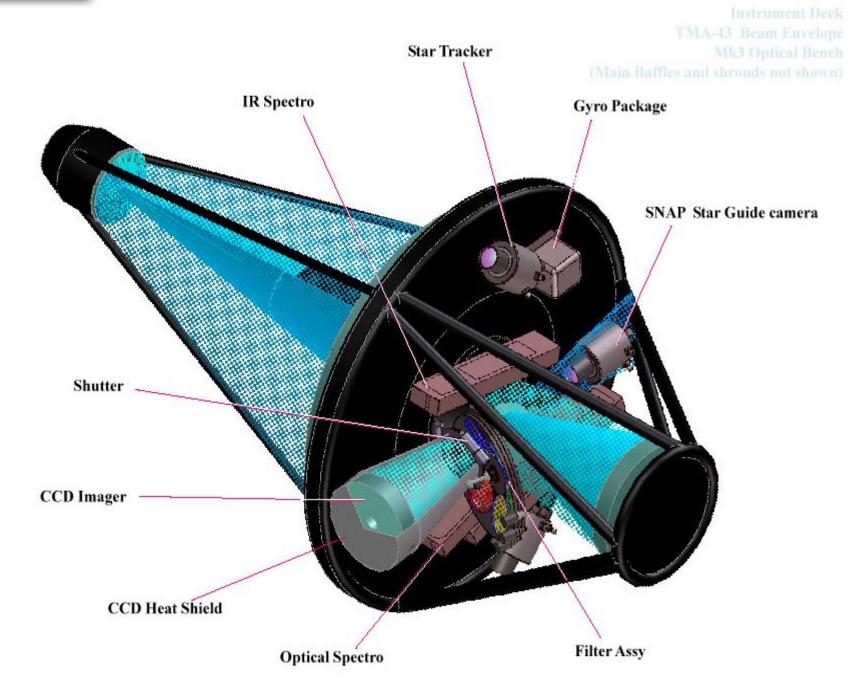
Cost,						82	-	-	7722	15	
Launch capacity, and Fairing volume			TMA-0x Off-Axis	TMA3x- Off Axis	TMA-0x	TMA-3x	TMA-40	TMA-43	TMA-51	TMA-55	
Space Transportation System	24,000 Kg	\$ 500 M								0	
Titan IVB/Centaur/SRMU	8600 Kg	S 250 M									We are HERE
Ariane 5	6800 Kg	\$ 120 M									
EELV-Heavy	6120 Kg										
H2-A	6000 Kg		0	0		0					
Proton	4800 Kg	\$ 50-70 M	0	0					0	0	Anything is possible
H2	4000 Kg	\$ 150 M								1	
Sea Launch I/Zenit 3	3300 Kg	\$ 50-70 M									Will certainly work, and we can expand the mission
Delta IV	2800 Kg							0			Works, and we have data points to show how
Atlas II ARS	3100 Kg							1			Will probably work but we haven't tried it.
Delta III (2 Stage)	2700 Kg						Ŏ				Might Work but will take a Heroic effort
Atlas II AR	2970 Kg	\$ 95 M					Ō		Ō	Ō	Won't work
Delta III (3 Stage)	2,799 Kg				Ŏ	Ŏ		Ŏ	Ŏ	Ŏ	
EELV-Small	1840 Kg			Ŏ	Ŏ	Ŏ	Ŏ	Ŏ	Ŏ		
Delta II 7925	1260 Kg	\$ 45 M	Ŏ	Ŏ	Ŏ	Ŏ	Ŏ	•	•	•	
	2012			_		-	-	100		1000	



Trade Space Overview



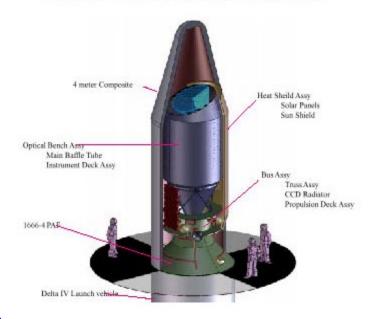


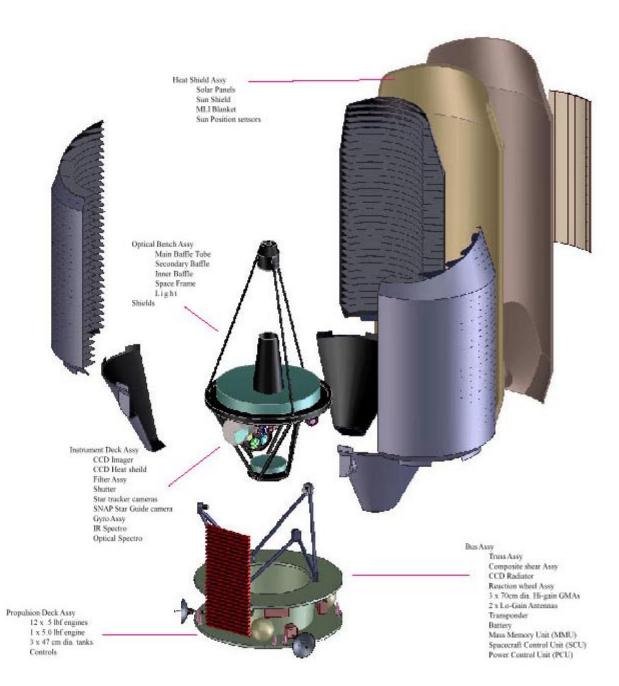






TMA-43 / Delta IV Launch Configuration

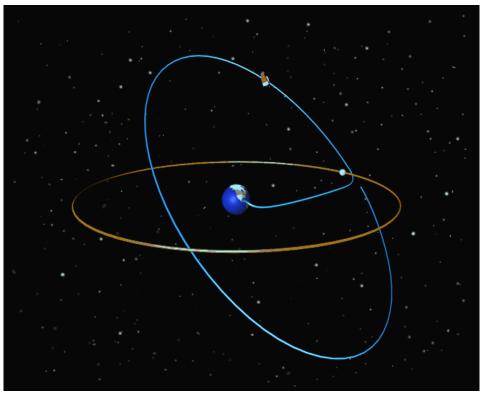




Orbit Optimization



- "Prometheus" Orbit Baselined Following Preliminary Trade Study
- Uses Lunar Assist to Achieve a 14 day (19 X 57 Re) Orbit, or 7 day (8 X 40 Re) Orbit with a Delta III 8930 or Delta IV-M Launch Vehicle
- Good Overall Optimization of Mission Trade-offs
- Low Earth Albedo Provides Multiple Advantages:
- Minimum Thermal Change on Structure Reduces Demand on Attitude Control
- Excellent Coverage from Berkeley Groundstation
- Outside Radiation Belts
- Facilitates Passive Cooling of Detectors
- Minimizes Stray Light in Telescope



Trade-Study



Feasibility & Trade-Study

Orbit	Radiation	Thermal	Telemetry	Launch	Stray Light	Rank
HEO/	Very Good	Passive	Med. BW	Fair	Dark	1
Prometheus						
HEO/	Very Good	Passive	Med. BW	Fair	Dark	2
L2						
HEO/	Poor	Passive	24 hr	Fair	Dark	3
GEO						
LEO/	Lowest	Mechanical	High BW	Fair	Earth Shine	4
Equator	Dose					
LEO/	High at	Mechanical	High BW	Excellent	Earth Shine	5
Polar	Poles					
LEO/	Lowest	Mechanical	High BW	Excellent	Earth Shine	6
28.5	Dose					

Selected Lunar Assist "Prometheus" Orbit

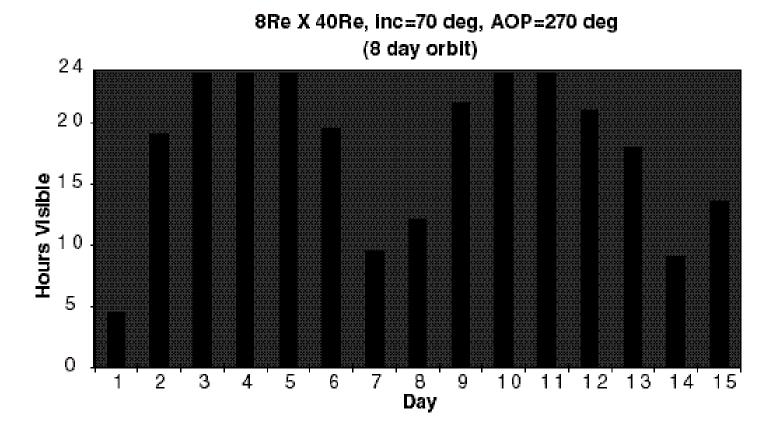
14 day orbit: 19Re Perigee/57Re Apogee

7 day orbit: 8Re Perigee/40Re Apogee

Telemetry



- High northern hemisphere orbit has excellent telemetry: ~50 Mbit/s for 19/57 orbit, >50 Mbit/s for 8/40 orbit
- 8 Gbit image every 200s № 40 Mbit/s (2:1 compression, no image stacking required)
- Data content is approx. 1/3 optical images, 1/3 spectroscopy, 1/3 IR photometry



MISSION OPERATIONS



Mission Operations Center (MOC) at Space Sciences Using Berkeley Ground Station

• Fully Automated System Tracks Multiple Spacecraft

Science Operations Center (SOC) at Lawrence Berkeley Laboratory Built Around the National Energy Research Super Computer (NERSC)

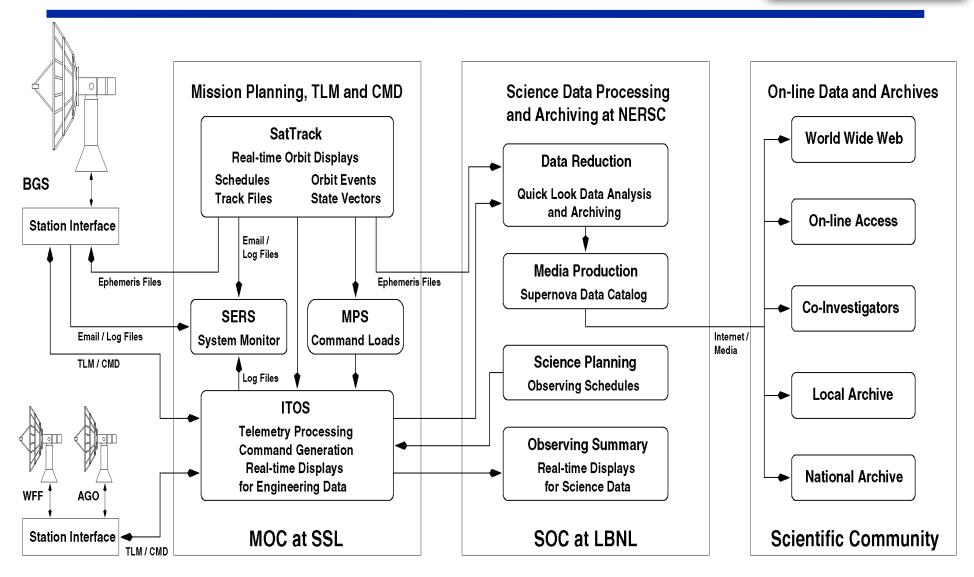
- Multiple Terabytes Data Storage
- High Speed Links to CPU Farms & Supercomputers
- Intensive Processing Done on Supercomputers

Operations are Based on a Four Day Period

- Autonomous Operation of the Spacecraft
- Coincident Science Operations Center Review of Data with Build of Target List
- Upload Instrument Configuration for Next Period

SNAP Ground Data System





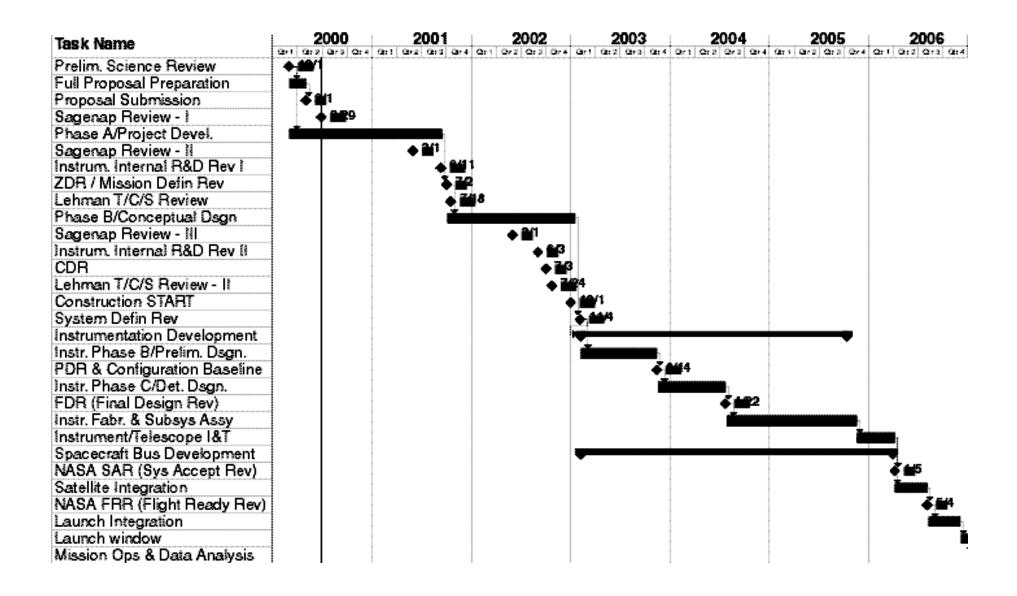
SNAP Ground Data System

Data Flow Layout

File: snap_gds.fig M.Bester, 19Nov99

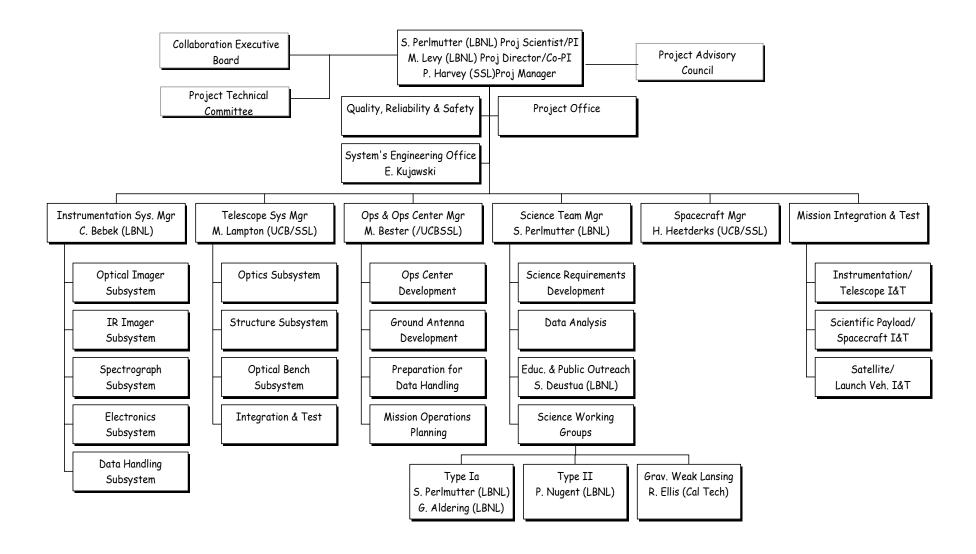
Preliminary Schedule











Public Interest



The recent high redshift supernova results of the accelerating universe have fired the public's imagination

High public interest in astronomy and cosmology



Summary



- Science Breakthrough of 1998
- Accelerating Universe / "Dark Energy" scientific impetus
- SNAP Project Setup
 - Working with Multiple Agencies (DOE, NSF, NASA)
 - Working with Multiple Collaborating Institutions
- Study Proposal presented to SAGENAP in March.
 - Very positive report
- Engineering work on SNAP is ramping up to establish costs and trade-offs
- Development of collaboration
- Development of key technology R&D